

ION CYCLOTRON RESONANCE APPLICATIONS IN MEDICINE

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ABSTRACT

Medical applications of ion cyclotron resonance (ICR) have been slow to appear, mainly because of the century-old reluctance to consider any pathway to wellness other than through biochemical/molecular biological means. Although the molecular explanation for ICR (or, alternatively, CMF for combined magnetic field) remains obscure, the effects that are observed are remarkable. Following the initial clinical success on bone repair, applications have surfaced in cancer treatment, regenerative medicine, control of oxidative stress, and potentially, neurodegenerative diseases, in effect representing a potential complete replacement for clinical pharmaceuticals. The theoretical explanations for the efficacy of resonance medicine that have emerged suggest that biologically contained water is the most likely interaction site.

INTRODUCTION

The notion that ion cyclotron resonance (ICR) plays a role in living things was formally introduced by the author¹ at a NATO meeting in Erice in 1985. This hypothesis followed a decade of fruitless attempts at trying to understand the experimental results independently obtained in laboratories headed up by Adey² and Blackman³, both groups showing that calcium ion transport in the central nervous system is perturbed by weak, low-frequency electromagnetic fields.

At the time, the radical nature of this ICR concept could not be overstated. Indeed, as a direct result, the author lost funding support, was denied access to better journals, and was even mocked at meetings. Nonetheless the simple truth and usefulness of this concept has long survived its severest critics⁴⁻⁶. There have since been dozens of confirmatory experiments, many

with clinical and biological applications, all supporting the thesis that this effect is intrinsically interwoven into basic biological function⁷.

The impact of ICR on biological thinking is best summarized by two of its consequences. First, it implies that biological processes are intimately connected to the geomagnetic field (GMF), to the degree where we can think of this field as an *aufseher* that oversees and regulates cellular homeostasis. Second, it reveals that biological processes can be rationalized, in the sense that certain physiological responses are shown to (numerically) depend on very specific physical variables, namely the charge-to-mass ratios of key cations. In the following, we expand on this second aspect of ion cyclotron resonance phenomena in biology and medicine.

THE ICR SIGNATURE

Much of the difficulty surrounding the recognition of ICR as a biological effector has occurred because of reluctance to admit experimental evidence in support of this concept without any corresponding reasonable explanation. There is no question that pending a satisfactory theoretical resolution the ICR phenomenon remains strictly empirical in nature, despite more than 50 experimental corroborations in at least a half dozen laboratories.

For each of these reports one finds a unique resonance signature, namely the classical expression for the cyclotron resonance frequency Ω , expressed as a radial frequency (Eq. 1),

$$(1) \qquad \qquad \qquad \Omega = \frac{q}{m} B_{DC}$$

where Ω , in terms of radians/second is equal to the product of the ion's charge to mass ratio and the magnetostatic field B_{DC} . This expresses the fact that a resonance condition exists when an ion moving in this DC field is also simultaneously exposed to a frequency f . In practice this is achieved by directing an AC field of frequency f parallel to the DC field. Probably the most important part of this relationship is its dependence on the physical uniqueness of the ion, specified by its charge-to-mass ratio. Thus the stimulation of different ionic types requires different combinations of frequency and magnetic field, in turn leading to different biological outcomes.

When expressed in terms of the more familiar frequency f given in Hz, the defining equation becomes

$$(2) \quad f = \frac{q}{2\pi m} B_{DC}$$

Using the q/m values for a number of critically important biological ions it is possible to obtain unique conditions on frequency f and magnetic field B_{DC} that are associated with any given ionic type. These are shown in Table 1.

The usefulness of this signature is shown in Fig. 1, where the resonance frequencies, in Hz, for a number of biologically critical ions are plotted against the magnitude of the magnetic field. One immediately notices that these ICR frequencies are all very small for magnetic intensities falling within the range of the earth's magnetic field, roughly 25-65 μ T. It is convenient to group these frequencies into the extremely low frequency, or ELF, range, commonly used in electrical engineering practice.

Equally important, frequencies this small can be readily involved in various endogenous activities in living things. The fact that biologically important ions can be readily connected to the earth's magnetic field does not in itself mean that the geomagnetic field ICR is actually interacting with living things. But it does imply that such interactions are quite possible. Indeed since 1985 dozens of laboratory experiments testing this possibility have found robust biological changes do occur when applying magnetic fields as indicated in Table 1. A short list of such changes that have been reported is shown in Table 2.

EXPLAINING THE ICR EFFECT

Almost immediately as the ICR hypothesis was offered in support of the Adey/Blackman work, it was dismissed on theoretical grounds. Among other criticisms, the most important shortcoming was that the viscosity in biological substances is much too high to allow resonance processes. Ion cyclotron resonance is commonly observed in physics, but only in vacuums, or at the very least, in low pressure gases. As applied to living things with much larger tissue densities the situation is made even worse for charged particles resonating at very low frequencies.

Nevertheless wide experimental support quickly made it clear that biological ions in many instances were indeed responding to the ICR signature. Possibly

the most striking thing about the continued criticism was the consistent denial of observed facts, often expressed as a statement of disbelief in the experimental reports, even outright assertions²⁰ that they constituted an example of “Pathological Science”. In retrospect these critics were lacking in the very quality that defines a scientist, namely curiosity about unexplained observations.

On the other hand, many scientists quickly accepted the abundant evidence and offered various attempts at explanation. In his original paper Liboff argued that the membrane ion channel was the likely interaction site. This was based on both the pivotal role played in cell metabolism by ion channels as well as the helical structure of the proteins that span the membrane in creating the channel structure. The latter fits the helical moiety of charged particles in cyclotron resonance. However there are various reasons why this picture is untenable, the most serious related to the great disparity between the ultrashort (10^{-10} s) transition times measured in channels and the resonance periods for low-frequency ICR (10^{-2} s). Additional explanations were suggested by Edmonds²¹ and by Zhadin²², both focused on the precessional motion of bound charged particles in magnetic fields, but these failed to provide an experimental handle with which to judge these explanations.

Lednev added greatly to the theoretical basis for ICR interactions²³ by not only focusing on calcium-binding proteins but also expanding on Eq. 1, finding a way to predict which values of the AC magnetic intensity are necessary for resonance to be observed. These proteins, best represented by calmodulin, are essential for cellular metabolism, playing a direct role in the use of calcium as a second messenger. The key factor in Lednev ‘s Ion Parametric Resonance theory was its dependence on a previously neglected observable, namely B_{AC}/B_{DC} , the ratio of AC to DC magnetic fields. This is a very convenient experimental yardstick with which to assess data. This same variable was used in subsequent theoretical models, first by Blanchard and Blackman²⁴, and later by Vincze et al²⁵. In the first case a wider set of proteins, apart from calmodulin, were explored. In the second, the theoretical explanation was not related to interactive proteins, but rather to magnetic field effects on ionic drift velocity.

Notwithstanding these theoretical approaches, it was a key experiment carried out in M N Zhadin’s laboratory¹⁶ that helped to better understand the nature of the ICR effect. While studying the ICR effect on polar amino acids in solution a sudden sharp increase in conductivity was found at the resonance

frequency (Fig. 2). This strange effect, independently confirmed²⁶⁻²⁸ at three other laboratories, points unequivocally to some sort of quantum-like phenomenon, the realization of which helps explain the inability of critics to find an answer by simply relying on electrical engineering.

Adding to the revelatory nature of Zhadin's experiment a second, equally profound fact emerged, namely that the ICR effect also occurs for AC magnetic fields that had previously been regarded as too small to be of any consequence. The experiment showed conclusively and was confirmed elsewhere that ICR magnetic fields as low as 40 nT are biologically effective, a fact that has enormous significance. To gain perspective one need only recall that in the early 1980s it was thought impossible that magnetic fields as low as 0.5 μ T (5 mG) could in general influence biological systems, and more specifically, the notion that power line magnetic fields could be tied to leukemia in children. Zhadin's experiment showed that when fields more than ten times smaller than this are deployed according to ICR conditions, they are biologically interactive.

Directly as a result of this data Emilio Del Giudice used quantum electrodynamics (QED) to propose a model²⁹ in which water exists in two states, one of which is enhanced by electromagnetic fields. He showed that microscopic water domains are formed which are devoid of internal ions. In this model the ions found on the surface of these domains are free, experiencing much smaller viscosities under magnetic resonance. Irrespective of whether the Del Giudice model is exactly correct, present thinking regards electromagnetic effects on water structure as the likely basic reason for ICR interactions.

BIOMEDICAL APPLICATIONS

Shortly after the ICR hypothesis was proposed, a device was designed around this concept to treat the problem of non-unions in bone, and was then approved by the FDA. This condition, also called pseudarthrosis, is one in which a small section of skeletal tissue fails to knit either following a fracture or because of congenital reasons. This problem can present considerable morbidity, often leading to amputation. Following the discovery³⁰ of piezoelectricity in bone by the Japanese surgeon/physicist team of Yasuda and Fukada, it became evident, for reasons still unclear, that small currents on the order of fractions of a milliampere, when applied to such discontinuities, are able to initiate the required bone growth process. C

A L Bassett subsequently explored the use of pulsed electromagnetic fields (PEMF) to deal with this condition³¹, obtaining a success rate of about 80%, and FDA approval, and at the same time demonstrating that this medical condition could be dealt with in a non-invasive manner. The ICR application³² of fields tuned simultaneously to Ca^{2+} and to Mg^{2+} was fully as efficacious as PEMF, but required power levels 50 times smaller, thereby allowing for greater device portability during treatment. A second FDA-approved ICR treatment is presently also used as an adjunctive procedure following spinal surgery. The ability of ICR-tuned magnetic fields to repair bone apparently derives from its profound effect (Fig. 3) on cartilage formation^{10,33}, well known to be the key precursor in the formation of new bone. Currently, some 25 years after the introduction of these devices to help repair bone, they are still being actively prescribed.

Another medical problem, distinctly different from bone, is effectively treated using a device designed according to ion cyclotron resonance principles. Chemotherapeutic depression, the ravaging effect commonly experienced by cancer patients following chemotherapy is treated by means of the Seqex device. In this procedure ICR magnetic fields tuned to selected ions are simultaneously applied to the whole body. It is believed that one mechanism of action involves the reduction of reactive oxygen species (ROS) one of the debilitating consequences of chemotherapy. Fig. 4 shows this effect³⁴ in a group of patients treated with Seqex. This device has also been used in treating a variety of other medical problems, with some positive results reported, in particular for multiple sclerosis (MS) and amyotrophic lateral sclerosis (ALS). However there is a need for adequate replications of these studies.

Yet another aspect of the Seqex treatment is its apparent effect on pH, an observation that is somewhat consistent with laboratory results elsewhere³⁵ indicating that electromagnetic fields are able to alter pH in water. Some extra credibility can also be attached to this claim because part of the Seqex regimen involves first finding the group of ICR tuning frequencies that alter the specific bioimpedance of the whole body, implying, quite remarkably, that these ICR applications are specifically altering the physical properties of biological water.

One very important application of ICR in medicine with great potential surrounds its use in regenerative medicine. Calcium cyclotron resonance (at

7 Hz) has been deployed to stimulate embryonic stem cell differentiation into cardiomyocytes¹⁹, triggering the expression of specific cardiac lineage promoting genes. As with the protocols adopted in many other ICR studies, when the same experiments were repeated at other frequencies one failed to find the same effect, demonstrating that application of the correct ICR frequency is the critical factor. This demonstrated for the first time that differentiation of human adult cardiac stem cells is feasible, opening the possibility for eventually doing away with heart transplants as the sole recourse when dealing with heart failure. It has further been noted that ICR regenerative techniques likely extend well beyond cardiac tissue with applications in all phases of tissue engineering.

Judging by the results in a number of animal studies, it is very likely that many additional clinical applications utilizing ICR will eventually be developed. One such example is the decades long work by F S Prato¹⁴ at the University of Western Ontario utilizing snails to investigate pain response. Although the model system appears very different from that which is human, the neurochemistry of the anesthesia reaction is quite similar. Based on this work it seems clear that ICR applications can greatly affect pain response, and might readily prove useful as an adjunct in current anesthesia procedures.

Another, completely different animal study³⁶ conducted in Novikov's laboratory, irradiated mice infected with Ehrlich ascities carcinoma with a selected group of ICR frequencies. When compared to control animals, the exposed mice were practically free of tumors, with an outstandingly significant level of statistical confidence in the results.

Novikov has also led the way in extending the discovery by Zhadin, mentioned above, showing that ICR magnetic combinations can affect certain physical properties of amino acids. In particular, he found that ion cyclotron resonance magnetic field combinations can affect proteins in a truly striking manner, hydrolyzing them into their constituent amino acid residues¹⁷. This represents something quite spectacular, considering that the thermal requirements for protein dissociation are orders of magnitude greater in energy than found in the ultraweak magnetic field combinations that were used. Directly as a result of this discovery it was demonstrated by Bobkova et al³⁷ that application of similar resonance fields to mice impacted with Alzheimers resulted in dissolution of the β -amyloid plaque residues that many feel are the biochemical reason for Alzheimers in humans.

There are many additional reports of this nature, showing that ICR magnetic field combinations are effective in dealing with various illnesses, with many unfortunately requiring further elaboration or human demonstration. For example, in one such case¹² it was demonstrated that ICR field combinations tuned to Ca^{2+} result in increased expression of insulin-like growth factor (IGF-II), a key factor in embryonic development. Properly extended, this work could potentially serve as a means of prophylactic prevention of Wilm's tumor in infants which is related to IGF-II expression in genetically impacted embryos.

DISCUSSION

It is ironic that so few applications of ICR to problems in the central nervous system have surfaced, considering that research in this general area was first stimulated by Adey's brain-related calcium efflux studies. Further there already is excellent experimental evidence that the nervous system makes great use of low-frequency electric signals, as in the endogenous generation of EEG signals. A number of laboratories^{8,38,39} have found changes in rat behavior, with enhanced aggressiveness for one type of ionic stimulation (Mg^{2+}) and passiveness for another (Ca^{2+}), with responses to both types of stimulation significantly different from the behavior observed under ambient magnetic field conditions. Cell culture studies^{11,40} also indicate that neuroblastoma cell proliferation is sensitive to ICR stimulation. For these and other reasons, one can readily anticipate there will be future approaches focused on using ICR to treat neurological problems ranging possibly from depression to neurodegeneracy.

It is not easy to explain the remarkable medicinal-like effects of ICR tuned magnetic field combinations. Current thinking relates these effects to much older reports that there are magnetic field effects on water, a contentious area long tainted by dubious claims. However the theoretical advancement by Del Giudice²⁹ following the discovery by Zhadin¹⁶ of magnetic effects in weak amino acid solutions, makes it very likely that water is intimately involved in the ICR phenomenon. We advance the idea that the important target of ICR magnetic fields, as used therapeutically, is a biologically specific water component that is structurally different from ordinary water. Although the physical characteristics attached to this second form of water are still in dispute⁴¹, one can nevertheless speculate that there is a need to maintain a sufficient fraction of this type of water in order to be in good

health, and that ion cyclotron resonance magnetic fields are effective because they act to increase its concentration in impacted areas. If there is indeed such a salubrious form of water, and its concentration is enhanced by application of appropriate ICR magnetic fields, then the curative properties of ICR stimulation are in principle very different from that of present medicine, in other words, more holistic than reductionist in flavor.

This observer has repeatedly championed⁴² the idea that the utilization of electromagnetic principles by evolution represents a virtually unexplored aspect of biology. We should not be surprised at the ability of magnetic fields to enhance wellness, given the underlying electromagnetic nature of living things. It remains to be seen just how inclusive this feature is and to what extent it either adds to or supplants our traditional approach to medicine, presently dominated by molecular biology and biochemistry. There is general agreement that the central nervous system is designed essentially as an electrical arrangement to facilitate information transfer. The utilization of ICR in living things may merely be one additional evolutionary solution to the fundamental question of how best to regulate life, given the constraints of physical law.

DEDICATION

This work is dedicated to the memory of my good friend and colleague, Emilo Del Giudice, one of the important contributors to this area of research, who not only realized the significance of ICR in biology (early on, in Erice, in 1985!) but went on to later relate our observations to the general problem of water structure.

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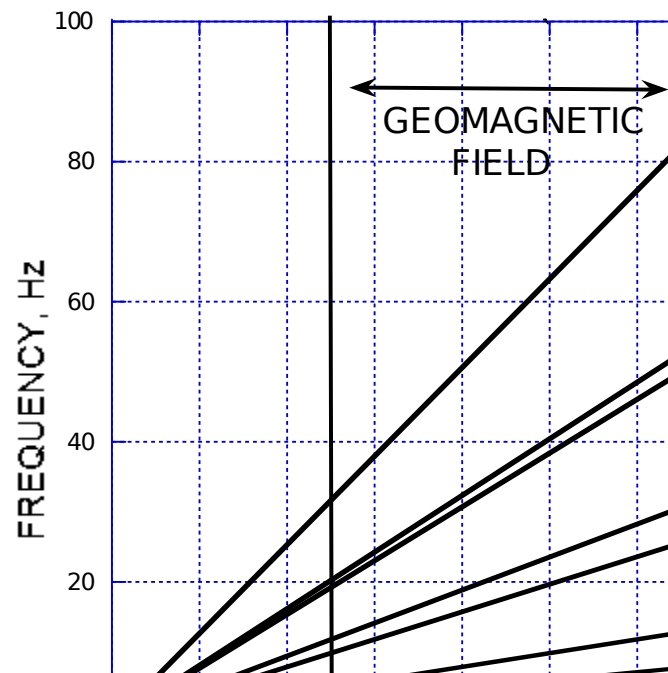


Fig.1. Ion cyclotron resonance frequencies plotted against B_{DC} for some critically important biological ions. The two vertical lines represent the approximate lower and upper bounds of the GMF at the earth's surface.

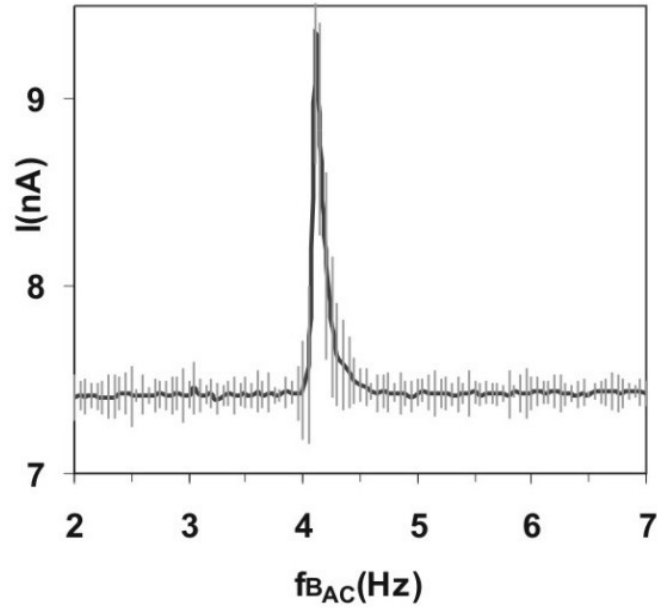


Fig. 2. A sharp increase in current in the Zhadin experiment occurs at the ion cyclotron resonance condition for glu^+ . For this specific run, $B_{DC} = 40 \mu\text{T}$ and the alternating magnetic field $B_{AC} = 50 \text{ nT}$. Frequency resolution is 0.05 Hz . (Pazur²⁶).

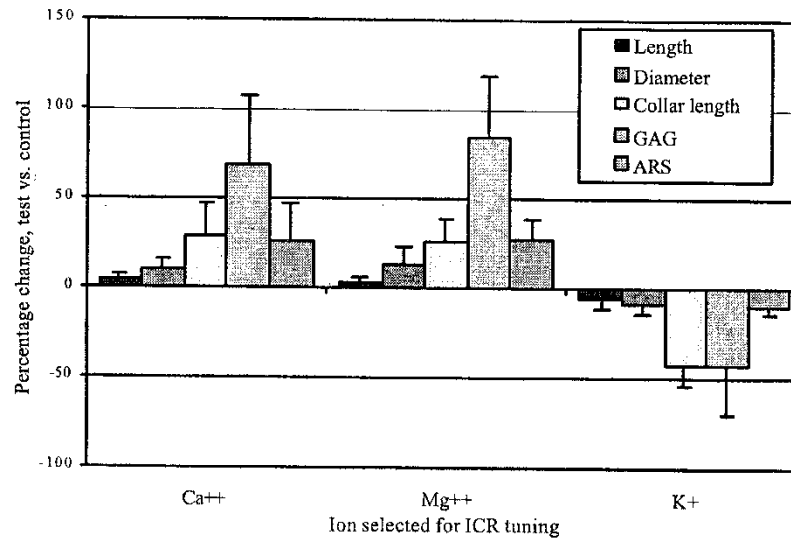


Fig. 3. Experiment on ICR stimulation of explanted cartilage showing the remarkable mobilization of GAG (glycosaminoglycans) following application of either Ca^{2+} or Mg^{2+} resonantly tuned magnetic field combinations, and the completely opposite result for K^{+} stimulation. (Regling et al³²).

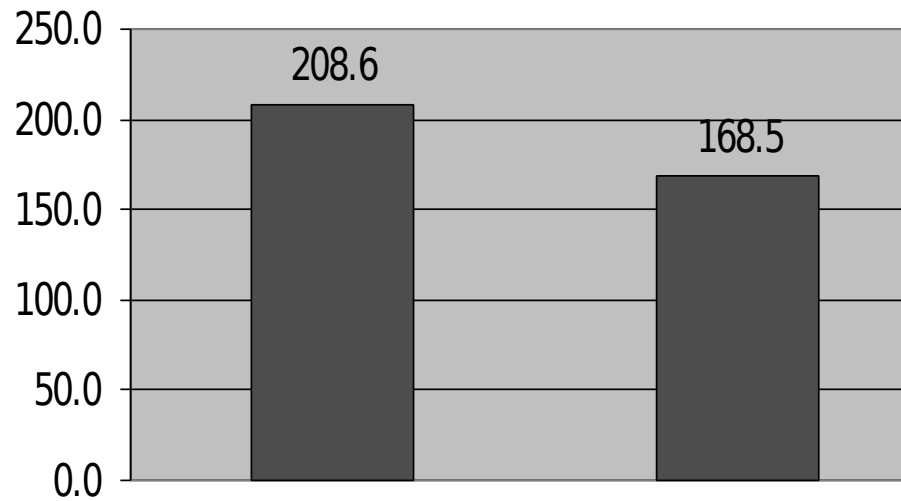


Fig. 4. Relative effects of Seqex treatment on oxidative stress on 38 lymphoma patients; before treatment (on left) and after (on right). Numbers refer to the FRAS-3 scale, a measure used in the evaluation of oxidative stress levels. (Rossi et al³³)

ION	q/m (C/kg x 10⁻⁶)	f/B_{DC} (Hz/μT)
H ⁺	95.76	15.241
Li ⁺	13.90	2.212
Mg ²⁺	7.937	1.263
H ₃ O ⁺	5.066	0.807
Ca ²⁺	4.814	0.766
Zn ²⁺	2.951	0.470
K ⁺	2.467	0.393
arg ²⁺	1.235	0.197
glu ⁺	0.747	0.119

Table 1. ICR conditions for selected biological cations. The charge-to-mass ratio, q/m, is given in terms of Coulombs per kilogram.

BIOLOGICAL MODEL	YEA R	REFERENCE
Rat behavior	1986	Thomas et al ⁸
Diatom motility	1987	Smith et al ⁹
Production of glycosaminoglycans in cartilage	1991	Smith et al ¹⁰
Neuroblastoma cell metabolism	1992	Smith et al ¹¹
Expression of Insulin Growth Factor II	1995	Fitzsimmons et al ¹²
Regeneration of planarians	1995	Jenrow et al ¹³
Analgesia in snails	1996	Prato et al ¹⁴
Rat EEG	1998	Vorobyov et al ¹⁵
Amino acid conductivity in aqueous solutions	1998	Zhadin et al ¹⁶
Protein hydrolysis	2001	Novikov et al ¹⁷
Growth Rate in plants	2005	Galland & Pazur ¹⁸
Stem cell differentiation	2009	Gaetini et al ¹⁹

Table 2. Representative list of reports indicating significant biological changes due to ICR exposure. Note the wide range of model systems in which ICR effects are observed, supporting the notion that a very basic interaction is at work.

